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Study of Large-Scale Vertical-Axis Wind Turbine Wake Through Numerical Modelling and Full-Scale Experiments

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Abstract

Vertical-Axis Wind Turbines (VAWTs) offer great perspectives to solve the issue of wake loss in wind farms as they are known to have a less stable wake. On a typical wind farm, wake effect accounts for a loss of Annual Energy Production which is still an open topic.

Numerical modelling and full-scale measurements have been carried out to study the 3D wake structures observed behind an operating VAWT. The comparisons showed that the wake is well predicted near the turbine but that downstream of the turbine, its dissipation is not well accounted for in the models. Indeed, as expected, current numerical models do not take well into account viscous diffusion and the reenergizing of the wake by the turbulent ambient air.

Numerical models can therefore be improved to predict the wake of a VAWT. It is expected that this work can lead to a significant improvement of a VAWT wind farm efficiency.

Objectives

- Compare the numerical simulations of a VAWT wake to measurements on a full-scale prototype at high Reynolds number.
- Improve the numerical models to predict more precisely the wake losses in a wind farm.
- Decrease the wake losses in a VAWT wind farm in order to make wind energy more competitive.

Methods

To study the 3D wake structures observed behind an operating VAWT, vortex models (ARDEMA) and a CFD model have been implemented for this analysis. ARDEMA is a set of a two dimensional (ARDEMA 2DS) and a three dimensional unsteady vortex codes (ARDEMA 3D) developed by ADWEN and NENUPHAR with subcontractings to Delft and the CORIA. CFD simulations are run with a software using a URANS (Unsteady Reynolds Averaged Navier Stokes) formulation.

NENUPHAR and DTU Wind Energy's WindScanner team collaborated in acquiring unique 3D wind field measurements around a 600 kW onshore prototype of an offshore floating VAWT concept. The mobile 3D remote-sensing laser-based WindScanner facility www.windscanner.dk provided 3D wake measurements around the large-scale onshore prototype of NENUPHAR operated at an onshore test site well-exposed to the strong Mistral winds near Fos-sur-Mer, Southern France. The WindScanners measured the mean and turbulence flow fields within and behind the 42 m tall and 50 m wide VAWT. The campaign resulted in a total of 37 wind field runs.

Figure 1 : View of the NENUPHAR's prototype and one of the three short-range WindScanners in operation around the NENUPHAR VAWT at Fos-sur-Mer, France

Results

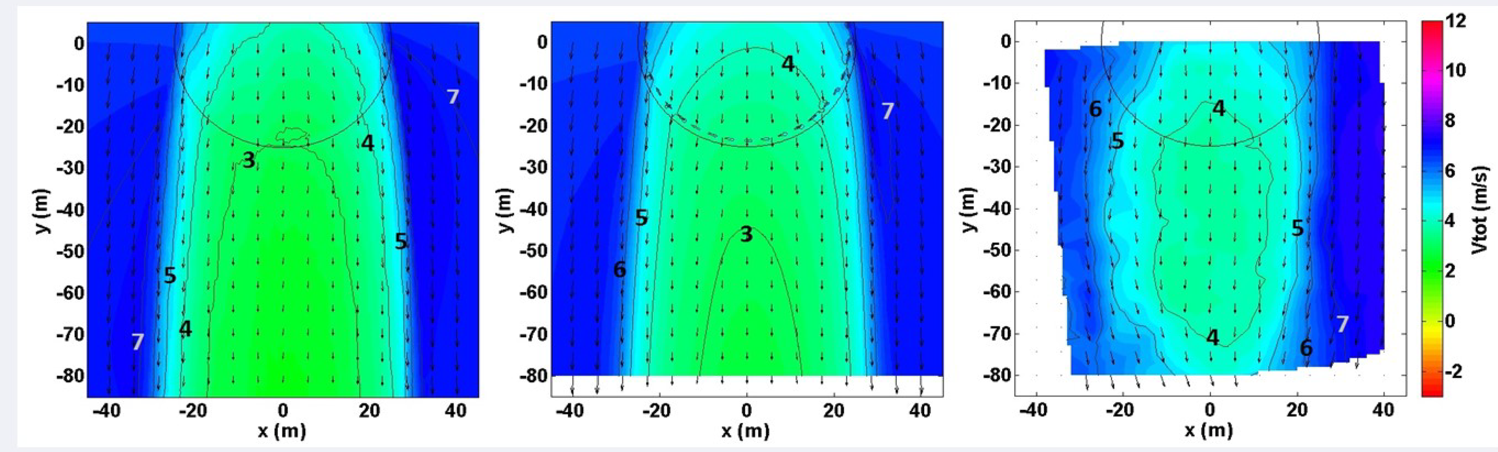

Figure 2: Mean wind field in a horizontal plane at hub height 27m. Comparison between ARDEMA 2DS, CFD 2D and WindScanner measurements from the left to the right. Operating conditions: Vwind=6,4m/s, high TSR.

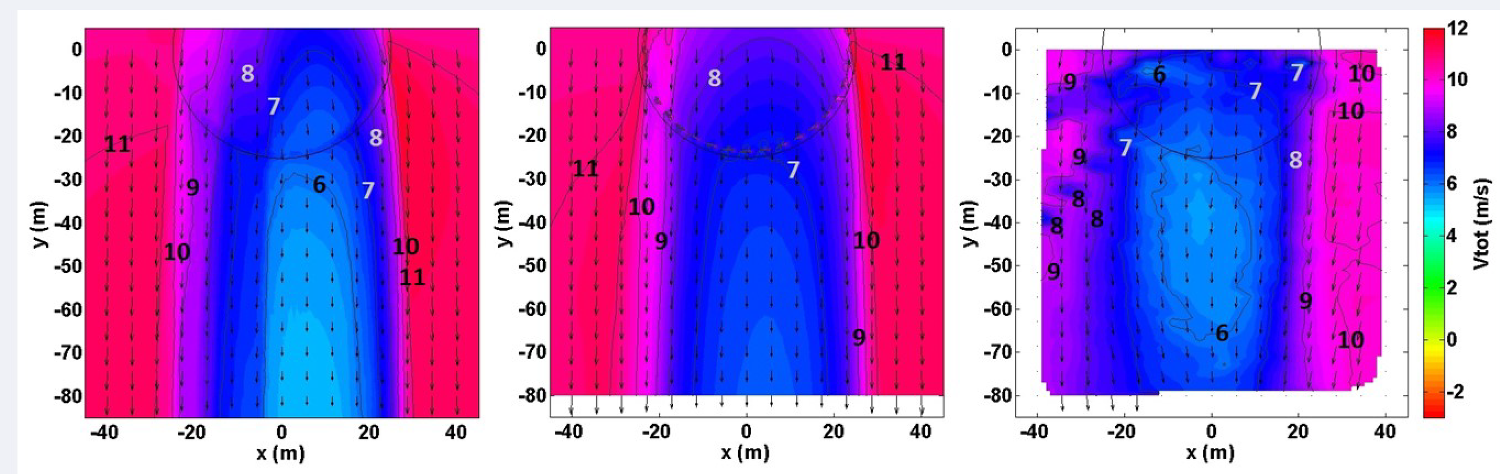

Figure 3: Mean wind field in a horizontal plane at hub height 27m. Comparison between ARDEMA 2DS, CFD 2D and WindScanner measurements from the left to the right. Operating conditions: Vwind=10,6m/s, low TSR.

Figure 2 and 3 show the wake of the NENUPHAR VAWT at high and low Tip Speed Ratio (TSR). We observe that the numerical models match very well except at low TSR. This could be expected as the dynamic stall modelling is semi-empirical in ARDEMA 2DS.

The comparison with the experimental results is fairly good near the turbine. The differences would need further investigations with measurements of the inflow upwind of the turbine. Far downstream, we observe that the wake dissipates more quickly in the experiment. This can be explained partly by the roughness of the test site and partly by the viscous diffusion and the mixing of the wake with the turbulent air which are not taken into account in the models.

With the conventions described in Figure 4, Figure 5 and 6 show the induced wind speed at the blades path over one rotation. The inflow comes from the azimuth 90° . The missing data correspond to invalid measurements due to reflections of the laser light from the wind turbine tower.

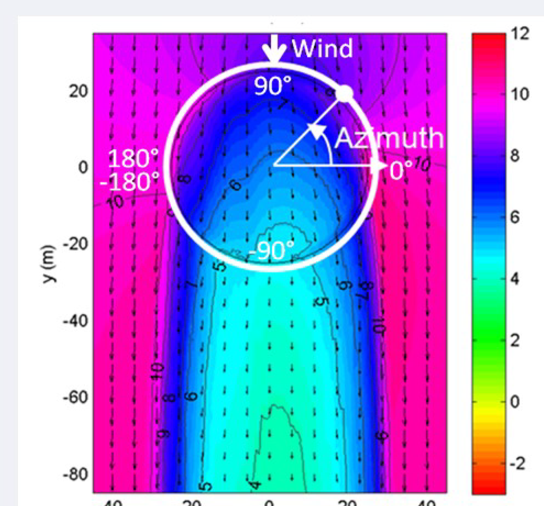

Figure 4: Azimuth conventions

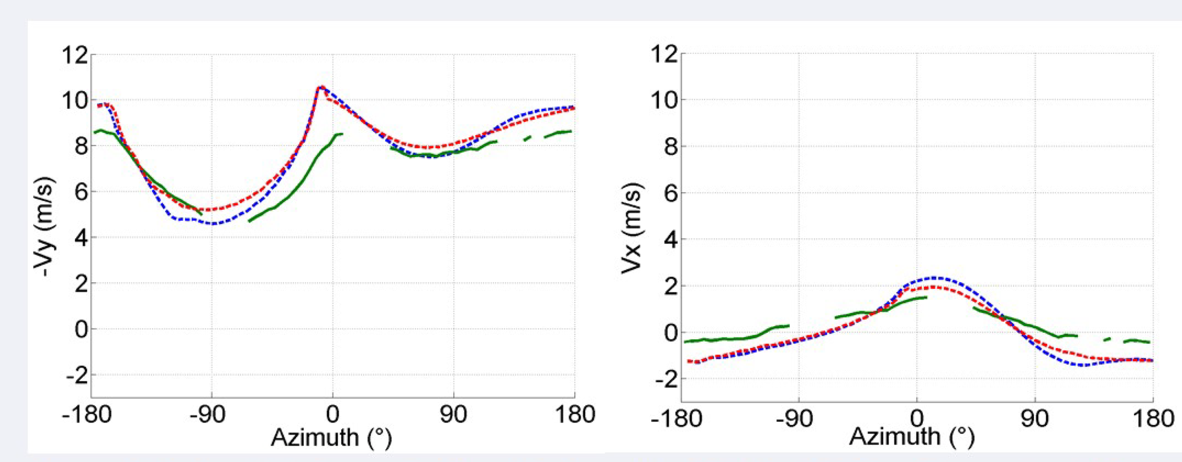

Figure 5: Induced wind speed at the blades path at hub height 27m. Comparison between ARDEMA 2DS (*in blue*), CFD 2D (*in red*) and WindScanner measurements (*in green*). Operating conditions: Vwind=9,6m/s, high TSR.

We observe a good match between the numerical simulations and the experiments. On the two left graphs, the first trough corresponds to the extraction of energy in the downwind zone of the VAWT. As expected, it is more pronounced at high TSR because it is closer to the optimal TSR.

On the second trough, which corresponds to the upwind extraction of energy, the models predict a stall of the blade around 90° which is not present on the measurements. This is due to the 3D nature of the swept blades of the VAWT which makes stall less pronounced.

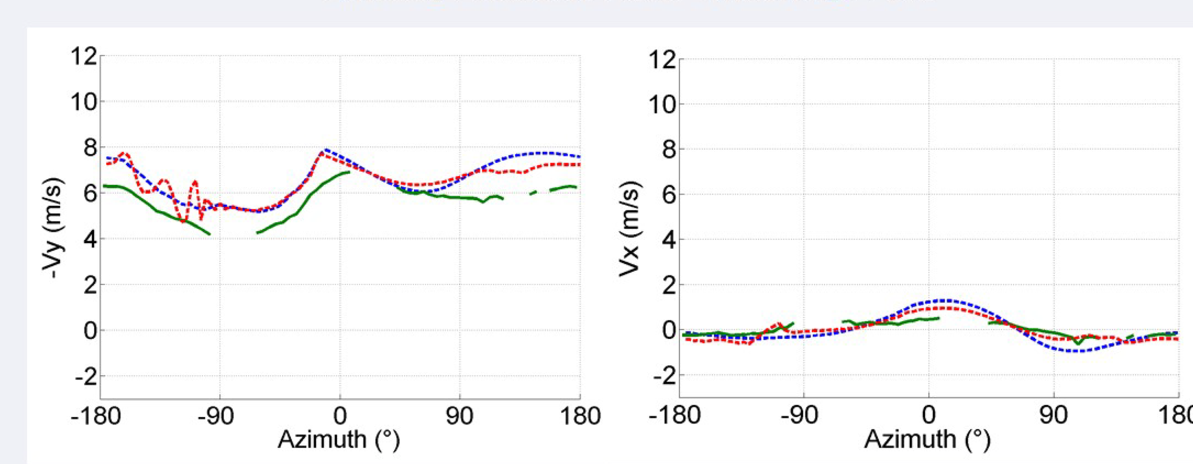

Figure 6: Induced wind speed at the blades path at hub height 27m. Comparison between ARDEMA 2DS (*in blue*), CFD 2D (*in red*) and WindScanner measurements (*in green*). Operating conditions: Vwind=7,4m/s, low TSR.

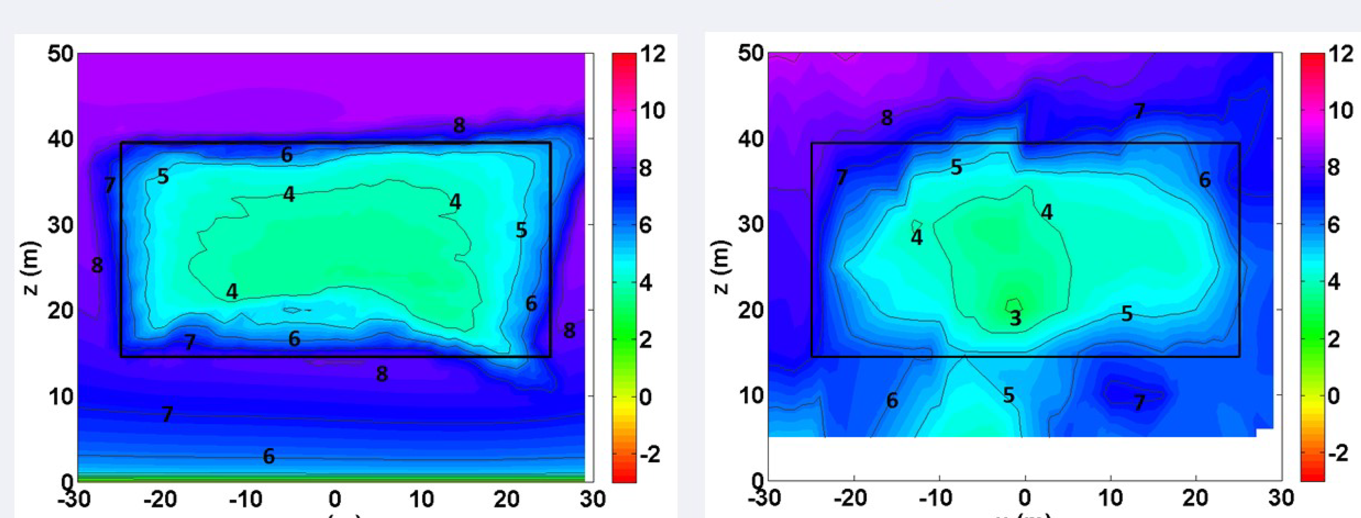

Figure 7: Mean wind field in a vertical plane at a distance of 0,5D behind the hub. Comparison between ARDEMA 3D (*top*) and WindScanner measurements (*bottom*). Operating conditions: Vwind=8m/s, low TSR.

In figure 7, ARDEMA 3D allows to compute velocity fields on a vertical plane placed at a distance of 0,5D downstream of the rotor center at a low TSR. ARDEMA 3D model includes blades and struts geometries but not the tower. The tower shadow and induced wake deficit can be clearly seen on the lower part of the experimental data.

The simulation considers a uniform mean wind speed with measured wind shear but without turbulence

The qualitative agreement is good although the wake structure is more pronounced in the simulation especially at the borders of the rotor projection (black rectangle). This is due to ambient turbulence and diffusion process, not yet modelled.

Conclusions

The comparisons between the numerical models and the WindScanner measurements showed a satisfying agreement in the near wake. The measurements on the NENUPHAR full-scale prototype provided valuable information about wake viscous diffusion and turbulent air mixing. It should now be possible to improve the numerical models to predict more precisely the far wake and improve the efficiency of VAWTs wind farm.

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References

1. Phillips, J. L., et al. "Wake effects within and between large wind projects: the challenge of scale, density and neighbours–onshore and offshore." *Proceedings of the European Wind Energy Association Conference.* 2010.
2. Dabiri, John O. "Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind turbine arrays." *Journal of Renewable and Sustainable Energy* 3.4 (2011): 043104.
3. Scheurich, Frank. *Modelling the aerodynamics of vertical-axis wind turbines.* Diss. University of Glasgow, 2011.
4. Beaudet, Laurent. *Etude expérimentale et numérique du décrochage dynamique sur une éolienne à axe vertical de forte solidité.* Diss. Université de Poitiers, 2014. French
5. Tescione, G., et al. "Near wake flow analysis of a vertical axis wind turbine by stereoscopic particle image velocimetry." *Renewable Energy* 70 (2014): 47-61.